APPENDIX E

BIOLOGICAL ASSESSMENT

BENTHIC HABITAT RESTORATION of the LOWER MAHONING RIVER ECOLOGICAL IMPLICATION

Part of the Reconnaissance Phase of the US Army Corp of Engineers' project on the restoration of benthic habitats in the lower Mahoning River, Northeastern Ohio

Prepared for

AWK Consulting Engineers
1611 Monroeville Avenue
Turtle Creek, PA 15145

by

Lauren Schroeder, Ph.D.
Department of Biological Sciences
Youngstown State University
Youngstown, OH 44555

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INTRODUCTION

The Mahoning River, for nearly ¾ of a century, supported one of the most intensely industrialized regions in the world (American Iron and Steel Industry, 1925). During the period from 1920 to about 1970 the river served 15 primary steel plants and 35 plants in steel-related industries. Peak water use by industry was over 1.5 billion gallons per day, using, discharging and reusing an equivalent of 4-5 times the normal river flow. The Mahoning River carried away the industrial waste from the heavy industry in the valley and the partially treated domestic waste from over 600,000 residents. The river received pickling liquor, electroplating discharges, coke quench water, cutting and lubricating oils, scale, and virtually any and all other waste materials that were most cheaply disposed of by discharge into the river. The Mahoning River received over 70,000 lb of cutting and lubricating oil each day. The water contained high concentrations of metals (copper, zinc, lead, chromium, iron, nickel and cadmium); cyanide averaged over 250 parts per billion (ppb), ammonia nitrogen over 3 parts per million (ppm), and phenols over 280 ppm. Biological Oxygen Demand (BOD) loading often depressed the dissolved oxygen to zero, temperatures regularly exceeded 100° F, and fecal coliform bacteria in excess of thirty thousand per ml were common (Ohio Department of Health, 1954, 1963, 1970; Harris, 1966; Mackenthum, 1969). The lower mainstem of the river, for most of this century, was heavily contaminated with industrial and domestic wastes that had a profound adverse effect on the biota of the river.

Mackenthum in 1969 found the number of species of bottom dwelling animals decreased from over 11 per square foot near Pricetown (RM 65), a relatively non-impacted area, to zero in many reaches of the lower Mahoning River between Leavittsburg and State Line (RM 40-12) (Mackenthum, 1969). Note that as in the report text, River Miles (RM) in this appendix are USACE miles. In some cases, OEPA river miles are given parenthetically after the USACE miles. The total number of bottom dwelling animals decreased from over 1400 per square foot near Pricetown to zero at many sites through the industrialized section of the river (Mackenthum, 1969). The river was so heavily polluted that only a few of the most pollution-tolerant species could survive. It is likely that during this period long stretches of the lower river were devoid of fish. The river was one of the most polluted in the United States, at a time when many rivers were highly polluted (in Stein, 1965).

Since the mid 1970's, under pressures from governmental agencies, both domestic and industrial pollution discharges into the Mahoning River have sharply diminished. Promulgation and enforcement of the Federal Clean Water Act (CWA) through the National Pollution Discharge Elimination System (NPDES) permitting process, has reduced the point source pollution of the Mahoning River. Concomitant with the implementation and enforcement of the NPDES much of the heavy steel industry along the Mahoning River has shut down. Domestic sewage is now processed through secondary sewage treatment plants for all of the major cities along the Mahoning River. The reduced pollution loading of the Mahoning River has resulted in marked improvement of the quality of the Mahoning River's water (OEPA, 1986, 1996).

However, despite improvements in the quality of the Mahoning River water, the river remains highly degraded, a legacy of heavy industrial use. The Ohio Department of Health has issued fish consumption and sediment contact advisories for the Mahoning River. The Mahoning River is only one of five rivers in Ohio that has an Ohio Department of Health Advisory against contact with the sediments. The other four are: the Little Beaver (mirex), Ottawa (polychlorinated biphenyls (PCBs)), Little Scioto River (polycyclic aromatic hydrocarbons, (PAH) and metals), and the Black River Harbor (PAHs) (Robert Davic, pers. comm.).

The most polluted section of the Mahoning River, in Ohio, is from Leavittsburg (RM 40) to the state line (RM 12). Although the chemical quality of the water flowing through this section of the river is relatively good, the biotic communities are highly degraded. Tissue from fish collected from the lower Mahoning River contain toxic substances (PCBs, and pesticides). The bile contains metabolites of PAHs, and blood elevated levels of enzymes that are indicative of exposure to toxic materials. The primary cause for the degradation and contamination of aquatic life in the lower Mahoning River is the toxic sediments, deposited during 75 years of heavy, unregulated industrial use.

MEASUREMENT of RIVER QUALITY BASED on BIOTIC COMMUNITIES

River biotic communities have evolved to produce complex, interdependent assemblages of plants and animals that are relatively stable in both species composition and function. However, river biotic communities developed largely in the absence of human influences and are sensitive to anthropogenic environmental alterations (pollution in the broadest sense). Even small changes in water chemistry, substrate composition, or river flow patterns can cause measurable changes in the structure of biotic communities, usually manifested by decrease in the number of species and an increase in the numbers of individuals of the most tolerant species. Because animals live continuously in the river they effectively sum the impact of pollution, thereby responding to pollution loading that may be missed by traditional chemical monitoring. Some chemicals are concentrated in the tissues of organisms, thus manifesting their toxicity even when concentrations in the water or sediments are otherwise undetected or considered non-toxic. The differences in animal communities of an impacted river (species composition and abundance) compared to communities in relatively non-impacted rivers is a good, perhaps the best, indicator of river impairment (OEPA, 1990, 1987a, 1987b). In addition to the absence of toxins and other pollutants, suitable places (habitats) are necessary for development of animal communities that are characteristic of unpolluted rivers. When the river biotic communities are comparable to the communities of similar but un-impacted rivers, then the water quality usually is similar to the un-impacted rivers (OEPA, 1990).

The Ohio Environmental Protection Agency (OEPA) has been among the first in the nation to develop water quality criteria for rivers that effectively incorporate measures of biotic communities as indicators of river impairment. Through the efforts of the OEPA, the importance of biotic community structure and function in assessing river quality has been encoded into Ohio law (Water Quality Standards (WQS), Ohio Administrative Code 3745-1). The normalization of the use of biotic indices in assessing river impairment by the OEPA is particularly valuable for assessing the effects of the proposed restoration of the Mahoning River because the methods are well tested, standardized, and widely applied (OEPA, 1987b). The OEPA recently completed an extensive study of the Mahoning River that includes biotic measures of impairment (OEPA, 1996). The OEPA's 1996 report provides not only an exceptionally good assessment of existing quality of the Mahoning River, but because of the extensive use of biotic indices, it also provides a means to empirically determine the expected changes in the river biotic communities in response to benthic habitat restoration.

The OEPA's methods rely primarily, but not exclusively, on three composite biotic indices, based on animal community structure and function. One is based on macroinvertebrates, the Invertebrate Community Index (ICI): and two are based on fish communities: the Index of Biotic Integrity (IBI) and the Modified Index of Well Being (MIwb). The ICI is determined from the composition of invertebrate species that colonize an artificial substrate that is anchored just above the sediments, over a six week period. The fish community, for determining IBI and MIwb, is sampled using electrofishing methods. Along with the biotic indexes, the Qualitative Habitat Evaluation Index (QHEI) is used to assess the physical attributes of river habitats. The rationale for development and use of the ICI, IBI, MIwb and QHEI are presented in OEPA, 1990, and Rankin, 1990. All four indices, along with chemical analyses of water, sediments, and fish tissues, have been determined by the OEPA for the Mahoning River and its tributaries (OEPA, 1996). Four other biotic measurements, included in the 1996 OEPA study, are relevant to assessing the current condition of the biota of the Mahoning River and for determining the effects of river sediment restoration. These are: (1) the sum of the Ephenoptera, Plecoptera, and Trichoptera taxa (mayflies, stoneflies, and caddisflies respectively), that occur on natural substrates in the river (EPT), (2) the percentage of fish that have deformities, fin erosion, lesions or external tumors (DELT), (3) fish tissue analyses for heavy metals and toxins, and (4) analyses of fish bile and liver for biomarkers. The EPT and DELT metrics are also incorporated into the ICI and IBI indices, respectively.

Qualitative Habitat Evaluation Index (QHEI)

Regardless of the physical and chemical quality of a river's water and its sediments, if the physical habitat is not conducive to fish and other animals, then the biotic health of the river will be degraded. In effect, the quality of the riverine habitat sets the upper limit to the quality of the animal communities. The "Qualitative Habitat Evaluation Index" (QHEI) (Rankin - OEPA, 1989) is used to assess river habitat quality. The index is based on six characteristics of river biotic habitats: substrate, in-stream cover, channel quality, riparian/erosion, pool/riffle, and gradient. QHEI scores range up to 100.

The QHEI correlates with the IBI and MIwb and is useful in predicting the expected IBI and MIwb in the absence of other degrading factors. There is a significant correlation between QHEI and IBI for 22 streams in the Erie Ontario Lake Plain ecoregion (EOLP) (the ecoregion that includes the Mahoning River) ($r^2 = 0.488$ $p < 0.01$) The corresponding exponential curve fit for the IBI is:

$IBI = 24.1e^{0.0082QHEI}$ $r^2 = 0.497$, $p = 0.014$ (calculated from data in Rankin, 1989, p 14).

(equation 1)

Where: r^2 = Pearson's correlation coefficient, a measure of how closely the variables are related

p = the probability of $r^2 = 0.497$ due to chance alone.

e = base of the natural logarithms

This equation will be used, in the report, to predict the maximum value for the IBI based on habitat quality for the Mahoning River. The QHEI score would set the upper limit to the IBI if there were no other limiting factors, i.e. toxins, excessive nutrients, turbidity, etc., adversely affecting the river biota.

Invertebrate Community Index (ICI)

Macroinvertebrates in non-impacted rivers are abundant, easy to collect, diverse in species, and are important functional components of river ecosystems, particularly for the transfer of energy from detritus and other organic materials to fish and other vertebrates. For these and other reasons (see OEPA, 1988) macroinvertebrate communities are used in the biotic assessment of water quality. Measurement of the macroinvertebrate community is with the "Invertebrate Community Index" (ICI). The ICI is based on nine measures derived from the number and kinds of invertebrate animals that colonize a standard artificial substrate (Hester and Dendy, 1962) over a six week period, plus the sum of Ephemoptera, Plecoptera and Tricoptera taxa (EPT) that are collected from qualitative samples of natural substrates. Since the EPT assessment is based on qualitative samples of the sediments and other substrates, it is relatively quick and easy to determine. The EPT itself is a good indicator of sediment quality and since many of the EPT immature stages live in or on the sediments, and many are very sensitive to degrading factors, the EPT will be treated as a separate measure of the effects of restoration on river quality.

Index of Biotic Integrity (IBI)

Fish are long-lived, have a wide range of sensitivity to pollution, are relatively easy to capture and identify, are the most familiar animal component of river communities, and are economically significant. For these and other reasons (see OEPA 1987b), measures of fish community structure and

function are used by the OEPA in assessing river quality. Two indices of river quality based on fish communities have been developed, the Index of Biotic Integrity (IBI) and the Modified Index of Well Being (MIwb).

The IBI is determined from 12 fish community metrics that incorporate species composition (number of: species, darters, sunfish, suckers and percentage of pollution tolerant species), trophic composition (percent of: omnivores, insectivores, and top carnivores), and fish natural history and condition (percent simple lithophils and percent DELT), (OEPA, 1989, 1987b).

DELT is an acronym for the frequency of occurrence in fish populations of fish with "deformities, eroded fins, lesions, or tumors" (see OEPA 1987b; 1987d). Causes of abnormalities include biotic infections, neoplastic disease, and chemical toxins (OEPA, 1987b). The DELT score is one of the metrics included in the IBI. However, it is also useful as an independent index for the Mahoning River because of the high concentrations of PAHs (polycyclic aromatic hydrocarbons), in the sediments, many of which are carcinogenic and cause tumors in fish (Baumann, 1989). DELT anomalies occur at low frequencies (< 3%) in non-impacted streams and increase with pollution loading.

The mean IBI for reference sites (non-impacted sites) for the ELOP ecoregion is 45, standard error (SE) = 1.1 with a range of 28-56 (OEPA 1987d). The minimum level for the IBI to meet Ohio Warm Water Habitat (WWH) use criteria for the EOLP ecoregion is 40 (OEPA, 1987d).

Modified Index of Well Being (MIwb)

The MIwb is based on the abundance, weight, and species composition of the fish community (OEPA, 1987b). The index excludes fish which are "highly tolerant" to pollution, hybrids, and exotic species, from the numbers and biomass components of the index. The calculation of the index includes the number of species, relative size, diversity based on numbers of each species, and diversity based on relative weight of each species:

$$MIwb = 0.5 \ln N + 0.5 \ln B + H\ (no.) + H\ (wt.)$$

where:

N = relative numbers of all species excluding species designated "highly tolerant"

B = relative weights of all species excluding those designated as "highly tolerant"

H (no.) = Shannon diversity index based on numbers

H (wt.) = Shannon diversity index based on weight

By combining numbers, biomass and diversity, the MIwb is a better indicator of river quality than when the individual indices (N or H) are used (Yoder, 1988). The MIwb has no upper limit, but seldom exceeds 10 (OEPA 1987b). The mean MIwb for reference sites in the EOLP ecoregion is 9.2, SE = 0.1, range = 7.8-10.2 (OEPA, 1987d). The minimum value for meeting WWH use criteria is 8.7 (OEPA 1987d).

Each of these four indices (QHEI, ICI, IBI, and MIwb) are measures of river ecological impairment that have been standardized against relatively non-impacted rivers in each ecoregion of Ohio (OEPA 1987d). The Mahoning River lies entirely in the Erie Ontario Lake Plain (EOLP) ecoregion, and has an OEPA Warm Water Habitat (WWH) use designation. The minimal values of biotic indices for achieving the WWH use designation for rivers in the EOLP ecoregion are given in Table 1. Criteria for other use designations are given for comparison.

Biocriteria	MWH	Impounded	**WWH**	EWH
QHEI	30-40	-	**60**	75
ICI	22	-	**34**	46
IBI	24	30	**40**	50
MIwb	5.8	6.6	**8.7**	9.6

Table 1. The biocriteria for river quality for rivers in the EOLP ecoregion that are sufficiently deep to be sampled from a boat (OAC, 1998). MWH = modified warm water habitat use. "Impounded" for reservoirs behind low head dams, WWH = warm water habitat use, EWH = exceptional warm water habitat use designation.

The characteristics of the QHEI and ICI developed for rivers are generally not applicable to impoundments and no criteria have been established for ICI in impounded reaches. However, fish community parameters do apply to impounded areas; hence, criteria for the IBI and MIwb are established for impounded reaches. The minimum QHEI for achieving IBI and MIwb in impounded areas is 45.

REFERENCES to ESTABLISH EXPECTED CHANGES in RIVER QUALITY FOLLOWING RESTORATION

The biotic index values of relatively non-impacted rivers in the same ecoregion are used by Ohio to set water quality goals. The Mahoning River has been designated a WWH use river (Table 1). To achieve WWH use criteria, the river should not only have adequate physical habitat (QHEI > 60), but also the pollution loading from point sources, non-point sources, and the sediments should be sufficiently low to permit development of

WWH biotic communities. Point source pollution of the Mahoning River has been reduced dramatically over the past 20 years; however, non-point sources remain significant (OEPA, 1986), primarily from rural and urban runoff, and sanitary sewer overflows.

The proposed restoration project will not affect existing point or non-point, except for sediment, sources of pollution. Thus the proposed benthic habitat restoration can not be expected to result in biotic community development at the level predicted by the QHEI. However, the river upstream from the proposed sediment restoration zone also receives point and non-point pollution, but the sediments are not nearly as contaminated as the sediments in the restoration targeted zone (TZ). Thus the quality of the biotic community in the river upstream from the TZ can serve as a reference zone (RZ) to judge the potential effects of benthic habitat restoration. The demarcation between the RZ and TZ is near the beginning of the Ohio Department of Health's advisory against contact with the River's sediments at about RM 41.5.

The OEPA sampling station at RM 39.0 (38.2) is at the transition between the relatively good to very poor river quality. The station at RM 39.9 (39.1) conforms to the standards for WWH use, while 0.9 miles downstream at RM 39.0 (38.2), below the outfalls from Copperweld and Thomas Steel Strip companies, the river quality begins to deteriorate and by RM 36.2 (35.4) the river quality is very poor. The river quality indicators at RM 39.0 (38.2), although lower than most stations upstream, are more similar to the upstream stations than to the downstream stations therefore, the samples from RM 39.0 (38.2) will be included in the RZ and the sampling stations down stream will be included in the TZ. For purposes of this discussion the demarcation between reference zone and targeted zone will be RM 39.0 (38.2).

Although the values of the biotic indices and other measures of water quality in the RZ do not fully meet the criteria for WWH use, they are much higher than for the TZ of the Lower Mahoning River (Table 2), and provide an expectation of river quality attainment, if the benthic habitat is restored to the quality of relatively un-impacted rivers in the EOLP ecoregion.

CURRENT STATUS of the LOWER MAHONING RIVER

The most extensive and recent data on the quality of the Mahoning River was compiled by the OEPA during the summer of 1994 (OEPA, 1996). The primary indicators of river health from these data are the biotic indices: EPT, ICI, DELT, IBI, MIwb, and QHEI (Table 2). The river has three major physical zones: (1) relatively unrestricted free flowing sections, (2) impounded reaches behind low-head dams, and (3) mixing zones where outfall from sewage treatment plants, tributaries and major industrial plants mixes with the Mahoning River's water. The data are separated in Table 2 according to these river characteristics.

	ICI			EPT		IBI			MIwb		DELT		QHEI	
	N	X	SD	X	SD	N	X	SD	X	SD	X	SD	X	SD
TZ (all)	13	9.1	4	1.7	1.7	17	22	5	5.5	1.3	14	7	64	13
TZ (NON)	12	**9.7**	3.9	**1.9**	2	12	**22**	3	**5.8**	1.2	**15**	6	**73**	6
TZ (IM)	1	6		nd		5	20	3	4.7	0.7	13	7	49	6
RZ (all)	10	30	8	5.7	2.3	12	28	4	7.6	0.7	5.6	3	58	14
RZ (NON)	8	**34**	5	**6.5**	1.5	7	**29**	6	**7.9**	0.8	**5.7**	3	**66**	11
RZ (IM)	2	22	3	5.5	0.7	5	27	2	7.1	0.4	5.4	3	44	4
WWH		**34**					**40**		8.7		**<3**		**60**	

Table 2. Indices of ecosystem health (ICI, EPT, IBI, Miwb), fish health (DELT) and habitat quality (QHEI) for the targeted restoration zone (TZ) of the Lower Mahoning River (RM 39 to RM 12), the reference zone (RZ) of the river just upstream from the TZ (RM 64 to RM 39), and WWH use minimum criteria. Data are from OEPA 1996. "all" = all data except from "mixing zones" ; "NON" = free flowing reaches of the river; "IM" = reaches impounded by low head dams; ICI = Invertebrate Community Index; EPT = sum of mayfly, caddisfly, and stonefly taxa; IBI = Index of Biotic Integrity; MIwb = Modified Index of Well Being; DELT = deformities, fin erosion, lesions and tumors on fish; QHEI = Qualitative Habitat Evaluation Index. N = number of samples, X = arithmetic mean, SD = standard deviation.

QHEI, Qualitative Habitat Evaluation Index

Water flow in over 50% of the TZ of the Mahoning River is impeded by low-head dams (Figure 1) (measured from topography maps for the Erie to Ohio canal, USACE, 1964). Deposition of sediments behind the low-head dams along with decreased stream velocity and drowning of rapids and runs, markedly reduce habitat quality. Despite the effect of the check dams the mean value of the QHEI for the TZ is 64, SD = 13, N = 17 (Table 2). There is no apparent trend in QHEI values with distance along the Mahoning River (Figure 2a). Except for the impoundments, the QHEI indicator of habitat quality for the TZ of the Mahoning River is relatively high, potentially exceeding the minimum values required to meet the WWH use criteria throughout the entire TZ. QHEI for the "free flowing" reaches of the TZ is 73 (SD = 6, N =12) and for the impoundment, the mean QHEI is 49 (SD = 6, N = 5) (Table 2). The effect of the low head dams is to lower habitat quality by about 24 QHEI units. The impoundments have a depressing effect on the quality of biotic habitats by reducing stream velocity, permitting the deposition of sediment that bury more favorable habitat of gravel and cobble, and reducing the number and extent of rapids, shoots, and river pools.

Relative to references:

The mean QHEI for all data in the RZ (RM 64 - 39) is 58 (Table 2). When the impounded river reaches are excluded the QHEI is 66, (SD = 11, N = 7) (Table 2). These values are less that for the TZ. The QHEI for non-impounded reaches are within the range for WWH use criteria in the EOLP ecoregion (Table 1). The QHEI of the impounded areas in the RZ (X = 44, SD = 4, N = 5, Table 2) are comparable to the impounded areas of the TZ (

X = 49, Table 2) and depresses the overall mean QHEI for the RZ by about 11 units. The physical habitat quality of the TZ equals or exceeds the physical habitat quality of the RZ and the minimum requirements for development of biotic communities that meet the WWH use criteria (QHEI > 60, Table 1).

ICI, Invertebrate Community Index

The ICI values are low throughout the TZ indicating poor to very poor river quality. The average ICI for the 12 sampling sites in the non-impounded reaches, excluding two mixing zone sites, of the TZ was 9.7 (SD = 4, N = 12) (Table 2). No sites from the TZ of the lower Mahoning River had ICI values above the minimum for WWH (Table 1, Figure 3). The average ICI value of the TZ (RM 39 - 12, X= 9.1, SD= 4, N = 13, Table 2) was much below the minimum criterion for WWH use (34) and is representative of poor river quality conditions (OEPA 1987b). The ICI increases from less than 6 at RM 36.2 (35.4), to a maximum of about 16 at RM 20.4 (20), then decreases to about 8 for the remainder of the river in Ohio (Figure 3).

Relative to references

The mean ICI for all data on the RZ is 30 (SD = 8, N = 9). When impounded sites and mixing zones are excluded the mean ICI for the RZ is 34 (SD = 5, N = 7, Table 2). This is equal to the minimum value required for achieving WWH use conditions (Table 1).

Because the ICI is based on the composition and function of benthic organisms that live on substrates, it is sensitive to the habitat quality of the river bottom. Excluding impounded areas, and despite a higher QHEI score for the TZ compared to the RZ, the

ICI value for the TZ is only 1/3 of the ICI value for the upstream RZ. The depression in ICI in the lower Mahoning River, in large part, is likely due to toxins in the sediments.

The mean ICI for the two samples from impounded areas of the RZ was 22, about 61% of the ICI value for non-impounded areas. The one sample from an impounded site of the TZ was 6 or 62% of the value for non-impounded reaches of the TZ and about 17% of the value for the non-impounded areas of the RZ. The loss of bottom habitat due to sedimentation behind the low head dams reduces the ICI values for both the RZ and TZ. In addition, the toxins in the sediments of the TZ depress the ICI values even further.

EPT, Sum of Taxa of Ephemoptera, Plecoptera, and Tricoptera

The EPT is one of the metrics incorporated into the ICI; however, because many (most) taxa of mayflies, stoneflies and caddisflies are intolerant to pollution, the EPT metric is particularly sensitive to toxic conditions in sediments. The EPT is relatively high for the RZ (X = 5.7, SD = 2, N = 10, Table 2, Figure 4) and X= 6.5 (SD = 2, N = 8) when samples from impoundments and mixing zones are excluded (Table 2). However, the EPT drops to zero in the TZ (Figure 4) and remains low throughout the lower Mahoning River (X = 1.7, SD = 1.7, N = 13, Table 2). Even when impoundment and mixing zone sites are excluded the mean EPT is very low (X = 1.9, SD = 2, N = 12, Table 2).

The EPT metric for the TZ is depressed more than any of the other biotic indices relative to the RZ. The EPT for the TZ averages less than 1/3 that of the RZ. The low EPT would be expected from rivers with toxic sediments, since many of the EPT organisms live in or on the sediments.

IBI, Index of Biotic Integrety

The IBI of the TZ (X = 22, SD = 5, N = 17, Table 2) is consistently below the minimum value for WWH (Figure 5). The IBI tends to decrease throughout the TZ declining from about 26 to about 17 from RM 36 to RM 14 (Figure 5). Impoundment does not have a significant effect on the IBI in the TZ (p = 0.281, Oneway Analysis of Variance (ANOVA)).

Relative to references

The IBI for the RZ (X= 28, SD = 4, N = 12) is greater than for the TZ, (p = 0.001, ANOVA). However, no sites in the RZ equaled or exceeded the WWH use criteria (Figure 5). The impairment of the river quality in the RZ is likely due to marginal habitat quality (QHEI = 58) and non-point pollution sources. Sediment restoration will not affect the non-point source pollution of the TZ, which likely carries a heavier load of non-point pollutants than does the RZ.

DELT, Fish Deformities, Erosion of Fins, Lesions, and Tumors

The DELT score is part of the IBI, but because it is responsive to the presence of chemical toxins in the sediments, it is included here as an independent measure of river quality. All of the 18 sampling sites for the TZ had DELT values that exceeded the WWH use criteria of 3% (Figure 6). DELT scores were lowest at the upper end of the TZ rising to about 8 between RM 36 and RM 30, then trending higher to over 24 by RM 20 and declining to about 14 for the remainder of the TZ (Figure 6).

The pattern of DELT scores with distance on the river is indicative of toxic sediments. While all sites in the TZ had high DELT scores the river section between RM 26 and RM 18 had exceptionally high DELT scores (>18). Both upstream and down stream from this "hot spot" the scores were much lower. If water borne toxins caused the high DELT scores then there should have been a tailing effect rather than a sharp discontinuity as observed between RM 21 and RM 16 (Figure 6).

Relative to References

Although the RZ had high DELT scores (X= 5.6, SD = 3, N =12) there were four sites where the DELT was 3 or less (Figure 6). The mean DELT for all data for the TZ was 14 (SD = 7, N =17), over twice as great as for the RZ and over 3 times the maximum value permitted to meet WWH use (Table 2).

MIwb, Modified Index of Well Being

The mean value of MIwb for all sampling stations in the TZ (X = 5.5, SD = 1, N = 17) was less than the minimum for WWH use (8.7, Table 1) and less than the mean for all sites in the RZ (X = 7.6, SD

= 0.7, N = 12, p = 0.001, ANOVA) (Table 2). The MIwb values for impounded reaches (X = 4.7, SD = 0.7, N = 5) of the Mahoning River were less than the values for the free flowing reaches (X = 5.8, SD = 1.2, N = 12, p = 0.048, ANOVA), (Table 2). As with the

IBI, the MIwb trended lower throughout the TZ, but was relatively high and constant through the RZ (Figure 7). The MIwb indicated that the diversity and productivity (standing crop) of the fish communities in the lower Mahoning do not conform to conditions for WWH use designation.

The relationship between habitat quality (QHEI) and MIwb was determined by regression analyses of data from the RZ. The best least squares fit was the exponential relationship:

$MIwb = 5.91\ e^{0.0043QHEI}$ $r^2 = 0.439$, $p = 0.014$ (Calculated for data from the RZ, OEPA, 1996)

(Equation 2)

Biomarkers

Ethoxyresorufin-o-deethylase (EROD) activity is an indicator of recent exposure to toxins such as PAHs, PCBs and other halogenated hydrocarbons. All fish samples from the TZ had elevated levels of EROD indicating exposure to toxic chemicals (OEPA, 1986). EROD activity peaked at over 400 units at river mile 29. EROD levels in samples from three sites in the RZ were not elevated above the "conservative indication for EROD induction" (<50 pmols EROD/mg protein for carp)(OEPA, 1996). Metabolites of two PAHs, benzo(a)pyrene (B(a)P) and naphthalene (NAPH), in fish bile were elevated above the USEPA reference levels (>500 ng/mg protein and 100,000 ng/mg protein, respectively) throughout the TZ (OEPA, 1996). The levels of metabolites from fish collected from sites within the RZ were near or below the USEPA reference values

(OEPA, 1996). Levels of bile PAH metabolites tended to increase throughout the TZ, with maximum concentrations of over 1500 and 300,000 for B(a)P and NAPH respectively at about RM 12 (OEPA, 1996).

ADV, Area of Degradation Value

The area of degradation (Rankin and Yoder, 1991) is the sum of the product of the mean deviation below a reference (e.g., WWH, or RZ) and the length of the river in which the deviation occurs.

$$ADV = SUM\,[(pIBIa + pIBIb) - (aIBIa + aIBIb)] * (RMa\text{-}RMb) \text{ for } a = 1 \text{ to } n$$

where: pIBIa = potential IBI at river mile a

pIBIb = potential IBI at river mile b

aIBIa = actual IBI at river mile a

aIBIb = actual IBI at river mile b

RMa = upstream river mile

RMb = downstream river mile

n = number of sampling stations

The ADV for the IBI and ICI illustrate the severity of river degradation in the TZ (Figure 8a and 8b).

Throughout the RZ, the ADV for IBI, except for one site at RM 54.8, remains low, but from about RM 39 on, the ADV increases sharply, accumulating to over 900 units by RM 12 (Figure 8a). The mean IBI-ADV for the TZ is about 35 units /mile while in the RZ it is only 8 units/mile. A similar pattern, but more pronounced, occurs when ADV is based on the ICI (Figure 8b). Once again the ADV is low and fairly constant until RM 39 where the value increases sharply throughout the targeted zone. The average ADV through the RZ is about 5 units/mile while in the TZ it is about 60 units/mile, or over 11 times greater.

The current (1994) biotic conditions in the Lower Mahoning are those of a heavily polluted river. Along the entire section of the river included in the proposed restoration zone, from about RM 39 to RM 12, none of the biotic indices equaled or exceeded the level required for the river to qualify for WWH use designation (Figures 2,3,5,6,7).

The Ohio EPA monitors the biological and chemical characteristics of all river systems in Ohio on a five year cycle. The Mahoning River was last examined by the OEPA during the summer of 1994 (OEPA, 1996). This comprehensive study of the Mahoning River system included up to 19 stations in the TZ. The data provide an excellent baseline from which the effects of dredging and other river improvement activities can be assessed. In addition, since the OEPA will repeat their study on the Mahoning River every five years the treatment effects will be monitored at no additional cost to the project. The next OEPA survey is scheduled for the summer of 1999.

Correlation between sediment pollutants and biotic indices of river quality.

Sediment contaminants analyzed by the OEPA include heavy metals, PCBs, PAHs, and chlorinated pesticides (Tables 10,11 and 12; OEPA 1996). For the purpose of this preliminary correlation analyses, the sediment contaminants were grouped as: total PCB, total PAH, total insecticides, and Cu, Cr, Pb, Cd, Ni and Zn. Because the concentrations of contaminant types in the sediment varies independently with location in the river, synergistic and masking effects preclude observing simple correlations between biotic indices of river quality and concentrations of individual pollutants. Therefore an index of sediment contamination that combined the concentrations, weighted to similar numeric magnitude, of all the major classes of sediment pollutants (TTOX) was constructed.

TTOX = total PCBs + 10 X total insecticides + 10 X total PAHs + (Cu + Cr + Pb + Zn)

	EPT	ICI	DELT	IBI	MIwb
TTOX	-0.673	-0.717	0.520	-0.645	-0.498
	(14)	(16)	(16)	(16)	(20)
	P = 0.008	P = 0.004	P = .039	0.007	P = 0.050

Table 3. Correlation coefficients for biotic indices of Mahoning River quality on an index of sediment toxicity. Top number is correlation coefficient, middle is the number of data points, and the bottom number is the level of significance, ie probability of a greater correlation coefficient.

The correlation between EPT, ICI, IBI and TTOX are highly significant ($P<0.01$) and the correlation between DELT, MIwb and TTOX are significant at $P<0.05$ (Table 3). A more refined index of sediment contamination that is based on relative toxicity, synergistic effects, and a more comprehensive chemical analyses likely would result in an even closer correlation between biotic indices and an index of sediment contamination.

Biotic indices are robust indicators of river quality and reflect the subtle interactions of sediment contaminants that may elude direct chemical analyses. The correlation between biotic indices of river quality and the index of sediment contamination is consistent with the hypotheses that contaminated sediments of the lower Mahoning River are the primary cause for river quality degradation. The results also support the use of biotic indices for measuring and monitoring river quality.

SUMMARY CURRENT CONDITION

Biotic indices: EPT, ICI, DELT, IBI, MIwb, biomarker studies, and ADV all indicate that the lower Mahoning River is highly degraded. All are consistent with contaminated sediments as the primary cause of the degradation. Over the entire reach of the TZ, about 27 miles, none of the biotic indices meet the minimum requirements for WWH use.

Depression of sediment-sensitive biotic indices "ICI, EPT" and elevation of toxic sensitive indices (DELT, and biomarkers) are clear indicators of the adverse effects that the sediment has on the biotic communities in the TZ. Negative correlation of biotic indices with sediment toxins (TTOX) are consistent with the sediments as the primary cause of river quality degradation.

Correlation analyses support the use of biotic indices as the primary measure of river quality. Despite the implementation of point source discharge regulations (NPDES permits, 1970s), shutdown of much of the heavy steel industry along the river (late 70s and early 1980s), implementation of secondary sewage treatment for all the major communities on the river (late 1980s and early 1990s) and the passage of time (about 20 years) the river biota remain highly degraded.

There are other factors that impact the biota of the TZ. Habitat quality is depressed by impoundments, continued pollution loading of the water from un-sewered, non-point source discharges, degradation of riverine wetlands, and pollutants that are scoured from contaminated sediments of the river's tributaries. However, very little improvement in ecosystem integrity of the lower Mahoning River can be expected from amelioration of current pollution discharges without marked reduction of the adverse effects of the river's sediment.

RESTORATION POTENTIAL

The potential for significant improvement in the quality of the Mahoning River from benthic habitat restoration is high. The quality of the river's water is good (OEPA, 1996), the potential quality of the riverine habitat, as measured by QHEI, is high (up to 73, versus the WWH criterion of 60, Table 2), and ongoing efforts to stabilize and improve the watershed through riparian easements and restoration (USEPA grant to the Mahoning County Metropolitan Park District) bodes well for the long term effectiveness of benthic habitat restoration.

This assessment of the potential for effective response of the Mahoning River to benthic habitat restoration is in conformity with the conclusions of Rankin (1996), who determined that the lower Mahoning River had either a "moderately high" or "high" potential for achieving WWH use criteria following benthic habitat restoration (Table 4). These terms reflect Rankin's subjective judgement based on three factors: (1) the QHEI values; (2) the quality of the watershed (i.e., the amount of agricultural versus urban land); and (3) the degree of stream channelization.

RM -RM	SEGMENT QHEI	RIVER QHEI	GRADIENT	USE	RESTORA-BILITY	CONFIDENCE
44 - 29	63	63	1.6	WWH	Mod-High	High
29 - 20	61.2	63	1.2	WWH	Mod-high	High
20 - 14	68	63	2.2	WWH	High	High
14 - 10	73	63	2.1	WWH	High	High

Table 4. Restorability of the lower Mahoning River to WWH use based on habitat characteristics. (Modified from Rankin, 1996). Rankin's (1996) "Restorability Rating" (RR) is based on habitat quality (QHEI) for the river segment, entire river and watershed, the river gradient and the use criteria restrictions.

EXPECTED EFFECTS of RESTORATION

The effects of restoration can be measured by monitoring the same biotic indices (reviewed above) that have been used by the Ohio Environmental Protection Agency in their assessment of the river quality in 1994 (OEPA, 1996). Based on the quality of the riverine habitat (QHEI) and biotic indices of the RZ a projection of the changes in the river biotic communities can be made. Three scenarios of restoration will be considered: (1) OPTION I, no action, (2) OPTION II, restoration of river benthic habitat and (3) OPTION III, restoration of river benthic habitat along with removal or breaching the low head dams.

Calculation of expected changes in river quality indices:

In each case for OPTION I, no change is expected, therefore the expected values of the biotic indices will be the same as the observed values and the change will be zero.

Increase in the QHEI from the removal of sediments (OPTION II) was estimated from the depression of the QHEI from silt and "embeddedness" in the OEPA 1996 report. Further increases in the QHEI would result from removal of low head dams (Option III). The effect of OPTION III on the QHEI also was estimated from the depression of QHEI due to exposing the now-drowned "riffles" and "runs" (OEPA, 1996).

The predicted effects for OPTIONS II and III on the other indices are based on the difference between the observed values of the indices in the TZ and the observed values in the RZ. The "observed" value for the TZ is the mean for all data points except from mixing zones (Table 2). The "expected" values are the means for all data points, except from mixing zones, from the RZ (Table 2) for OPTION II and data from un-impounded sites (Table 2) from the RZ for OPTION III.

In addition, expected values for IBI were calculated based on the expected QHEI scores using equation 1. Similarly expected values of MIwb were calculate based on the expected river QHEI using equation 2. Since equation 1 was empirically determined using data from relatively un-impacted reference rivers in the EOLP ecoregion, calculation of IBI represents the potential value in the absence of other limiting factors. The MIwb regression equation (equation 2) was determined empirically from data from the RZ of the Mahoning River, therefore it represents expected values of MIwb in the presence of some ambient pollutants.

Table 5a. QHEI, ICI, and EPT

	QHEI				ICI				EPT			
ACTION	OBS	EXP	CHA	%	OBS	EXP	CHA	%	OBS	EXP	CHA	%
None	64	64	0	0	9.1	9.1	0	0	1.7	1.7	0	0
Sediment only	64	69	+5	8	9.1	30	+21	230	1.7	5.7	4	235
Sediment + dams	64	73	+9	14	9.1	34	+25	274	1.7	6.5	4.8	282

Table 5b. IBI

	IBI						
	BASED on RZ				BASED on QHEI		
ACTION	OBS	EXP-RZ	CHA	%	EXP-QHEI	CHA	%
None	22	22	0	0	22	0	0
Sediment only	22	28	6	27	42	20	91
Sediment + dams	22	29	7	32	44	22	100

Table 5c. MIwb

	MIwb						
	BASED on RZ				BASED on QHEI		
ACTION	OBS	EXP-RZ	CHA	%	EXP-QHEI	CHA	%
None	5.5	5.5	0	0	5.5	0	0
Sediment only	5.5	7.6	2.1	38	7.9	2.4	44
Sediment + dams	5.5	7.9	2.4	44	8.1	2.6	47

Table 5. Expected change in QHEI, ICI, EPT, IBI, and MIwb resulting from three restoration scenarios: "no action", restoration of the benthic habitat (sediment only), and restoration of the benthic habitat and removal of low head dams (sediment and dams). Expectations for change in QHEI, ICI, and EPT are based on comparison of the reference zone (RZ) to the targeted zone (TZ) using the 1996 OEPA data (excluding data from mixing zones) (OEPA, 1996). Expectations for change in IBI and MIwb are based, in addition to comparison with the RZ, also on habitat quality (QHEI). OBS = observed (OEPA, 1994); EXP = expected values resulting from action, CHA = change in mean index value, % = expected percentage change of the index from the action, EXP-QHEI = expected values based on the quality of the physical habitat.

RESTORATION OPTIONS

OPTION I. No Action

A "no action" option would result in amelioration of the contaminated sediments if: (1) the contaminated sediments are buried by deposition of uncontaminated materials, (2) contaminated sediments are scoured out and transported down stream, or (3) toxins in the sediments are bio/chemically degraded, reducing sediment toxicity. None of these ameliorating mechanisms appears to be occurring. Because of the many reservoirs on the river and its tributaries, the sediment load in the river is low and deposition is minimal (Havens and Emerson, 1972). Conversely combination of low head dams on the river and flow control by the Army Corps of Engineers prevents significant sediment scouring. Between 1962 and 1975, Havens and Emerson (1975) estimated that a net increase of 11,400 cu yd of sediment occurred between RM 0 and RM 40. This amounts to about 4% (calculated from data in Havens and Emerson, 1975), of the total sediment in the river in 1975, and is probably within the limits of measurement error.

Many of the most toxic materials in the sediments, heavy metals, PCBs and PAHs are refractory to bio/chemical degradation. This is exacerbated by the anoxic and low light conditions in the sediments, especially in the impounded reaches of the river rendering them even less favorable for degradation of PAHs and other refractory organic compounds (Cerniglia and Heitkamp, 1989). The consequence is that contaminated sediments are quite stable and little change in toxicity or habitat quality can be expected from a "no action" scenario. This is supported by the small change in sediment pollution levels between the 1984 and 1994 EPA studies (OEPA, 1986,1996), and more recent sediment sampling (Schroeder, 1996 unpub, Testa, 1997, Martin 1998 unpub.).

Even if "no action" resulted in a reduction in toxicity of the sediments the silt and sludge character of the sediments provides poor habitat for river organisms and would prevent development of biotic communities indicative of WWH use river quality. The no action option would result in only minor improvements in the river quality. It is likely that the sediments would remain toxic for decades and the biota would remain severely degraded.

OPTION II. Restoration of Benthic Habitats

OPTION II is the removal of the toxic sediments and replacement with substrate, or exposure of substrate, that is characteristic of non-impacted rivers in the EOLP ecoregion. Replacement of the

sludge and silty sediments with more suitable riverine substrates would result in a small, about 5% increase, in the QHEI score to 69 (estimated from QHEI analyses, OEPA, 1996). However, removal of the toxic sediments would have a dramatic effect on the invertebrate community. The invertebrate community would be expected to recover to at least the quality exhibited in the river just upstream of the targeted area. The expected increase in ICI is 230% of the 1996 value, and the EPT is expected to increase by 235% over the 1996 scores (Table 5a). This would be near the criteria for WWH use river quality. Since the intrinsic habitat quality (QHEI) of the TZ is greater than for the RZ (Table 2) and the restoration of the sludge and silty substrate would further improve the habitat, the ICI and EPT expectations are conservative. It is likely that restoration of the sediments would bring the ICI scores within the criteria for WWH use.

The fish community would also respond significantly to removal of toxic sediments. Based on the current community structure in the RZ, the expected change in IBI from sediment restoration would be an increased value from 22 to 28, a 27% increase in the index (Table 5b).

Change in the IBI, in response to improving river quality, is slower than for the ICI because the life cycle of fish is much longer and the reproductive potential is usually much less than for invertebrate organisms. Also in areas where pollution or other degrading factors have been alleviated there is a time delay as previously excluded fish species colonize the river. The rate of colonization depends *inter alia* on distance from existing populations and barriers to movement, e.g. river check dams.

The potential value for the IBI based on the quality of habitat is 42 or an expected increase of about

91 % (Table 5b). However, estimating the IBI for the RZ based on the regression equation for IBI = f(QHEI) (equation 1) overestimates the actual IBI of the RZ by 25% (actual IBI = 28, calculated from QHEI, IBI = 35). Thus, other degrading factors remain in the river that prevent full attainment of the habitat potential for biotic community development. If the QHEI-based IBI (42) is adjusted for other, non-sediment related mitigating factors, the predicted IBI for the TZ is 31 or an increase of 9 or 41%.

The MIwb, another index of biotic community impairment based on fish, also would increase following sediment restoration. The MIwb score based on the values for the RZ would increase from 5.5 to 7.6, a 38% increase (Table 5c). When based on the relationship between MIwb and QHEI (equation 2) for the RZ, the expected MIwb for the lower Mahoning River predicted from the existing QHEI scores is 7.9 or a 44% increase (Table 5c). Since equation 2 was determined empirically using data from the RZ, it already includes the effects of existing pollutants.

The DELT scores of fish collected from the RZ are about twice the maximum value for WWH use designation, but are only about ½ the mean value for fish in the TZ (Table 2). Sediment restoration would reduce the DELT score by about 50% but it would likely remain above the value for WWH use designation.

OPTION III: Benthic Habitat Restoration and Removal of Low Head Dams.

Removal of the low head dams would improve habitat quality by increasing stream velocity, increasing exposure of substrate with high habitat quality, prevent deposition from covering restored

substrate habitat, and provide easy access for fish to colonize the river. Removal of the dams would result in an increase over OPTION II in all indicators of biotic community development (Table 5), except for the DELT. In both the RZ and the TZ there is no significant difference in DELT scores between impounded and non-impounded reaches (Table 2). Removal of the low head dams in addition to benthic habitat restoration, would increase the QHEI by 4 points (6%), ICI by 4 points (44%), EPT by 0.8 points (47%), IBI by 2 points (9%) and MIwb by 0.2 points (4%).

The potential IBI calculated using equation 1 is 44. This exceeds the minimum criterion for WWH use of 40. The MIwb calculated using equation 2 is 8.1, within 10% of the minimum WWH use criterion of 8.7.

Habitat degradation in impoundments behind low-head dams result from: drowning of riffles and runs, entrapping silty sediments that embed or bury more favorable substrates, and depression of the dissolved oxygen from oxygenation of entrapped organic matter. Leaving the low-head dams in place will: (1) constrain development of river communities by lowering the quality of the habitat (2) cause the restored communities to degenerate through degradation of the physical habitat (embedding and burying favorable substrate) and (3) reduce water aeration and dissolved oxygen, especially at the sediment water interface in the impoundments behind the low-head dams.

MONITORING THE EFFECTS of RESTORATION

The Mahoning River Basin is scheduled for regular (every 5 years) comprehensive study of river quality by the Ohio Environmental Protection Agency. The last study of the river biota was during the summer of 1994. The next scheduled study is during the summer of 1999. These investigations will provide a rigorous evaluation of the effects of restoration.

During the interim periods between the OEPA studies, monitoring of the biotic communities should continue. Although not a primary index used for assessing river quality, the EPT index is the most sensitive to the sediment pollution loading and should respond most rapidly to restoration. The EPT is relatively easy to determine and relatively inexpensive. The EPT should be determined each year for sensitive sites throughout the TZ and at selected sites in the RZ. In addition, ICI should be measured for select sites (fewer than for the EPT) in the TZ and RZ. These two measures, taken annually, along with the scheduled longer range OEPA studies will provide an adequate measure of the short term and long term effect of sediment restoration of the TZ.

Disturbance of potentially toxic sediments may warrant additional monitoring to assure that the process of restoration does not harm healthy communities down stream from the TZ. The details of this would be described in the "Feasibility Study" after the method of restoration is chosen.

There may be scientific and technical merit to develop a more comprehensive monitoring and assessment regimen to describe the river's recovery in order to describe the dynamics of community changes that occur during and following the restoration project.

CONCLUSIONS:

1. The lower Mahoning River for most of the 20th century was highly polluted.
2. There is abundant data on the water, sediment, and biotic quality of the Mahoning River.
3. Despite successful point source pollution abatement activities, the lower Mahoning River (RM 39 - RM 12) remains highly degraded.
4. The primary cause of the degradation of the lower Mahoning River is contaminated sediment.
5. Metrics are available to assess the biotic community integrity of the Mahoning River.
6. These same metrics can be used to predict the biological impact of benthic habitat restoration of the lower Mahoning River.
7. Sediment remediation alone would markedly improve the biotic community structure and

   function of the Lower Mahoning River. It is likely that sediment remediation alone

   would bring the biotic indicators to near the values required for WWH use designation.
8. Removal of the low head dams would further improve the community indices with a high likelihood of achieving WWH use designation for all OEPA community-based biotic indices (except DELT).
9. Restoration should remove the "no-contact" advisory on the Mahoning River.

10. In order to determine if restoration would remove the "no consumption" advisory, monitoring of several generations of fish is likely to be necessary.
11. The OEPA will provide regular comprehensive studies of the water and biotic quality of the Mahoning River which will provide an unparalleled long-term monitoring of the effects of sediment remediation on the biotic community quality.
12. Annual EPT and ICI monitoring will track the effects of sediment remediation on the river biotic communities.
13. The OEPA will provide regular comprehensive studies of the water and biotic quality of the Mahoning River which will provide an unparalleled long term monitoring of the effects of sediment remediation on the biotic community quality.
14. There may be scientific and technical merit in a more comprehensive biological monitoring of the effects of sediment restoration on the quality of the river.

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Rankin (1996) developed a "Restorability Rating" (RR) based on habitat quality as assessed by the QHEI. His RR is based primarily on the river segment, entire river and watershed habitat quality, and river gradient. Rankin applied the RR to the Mahoning River (Table 6).

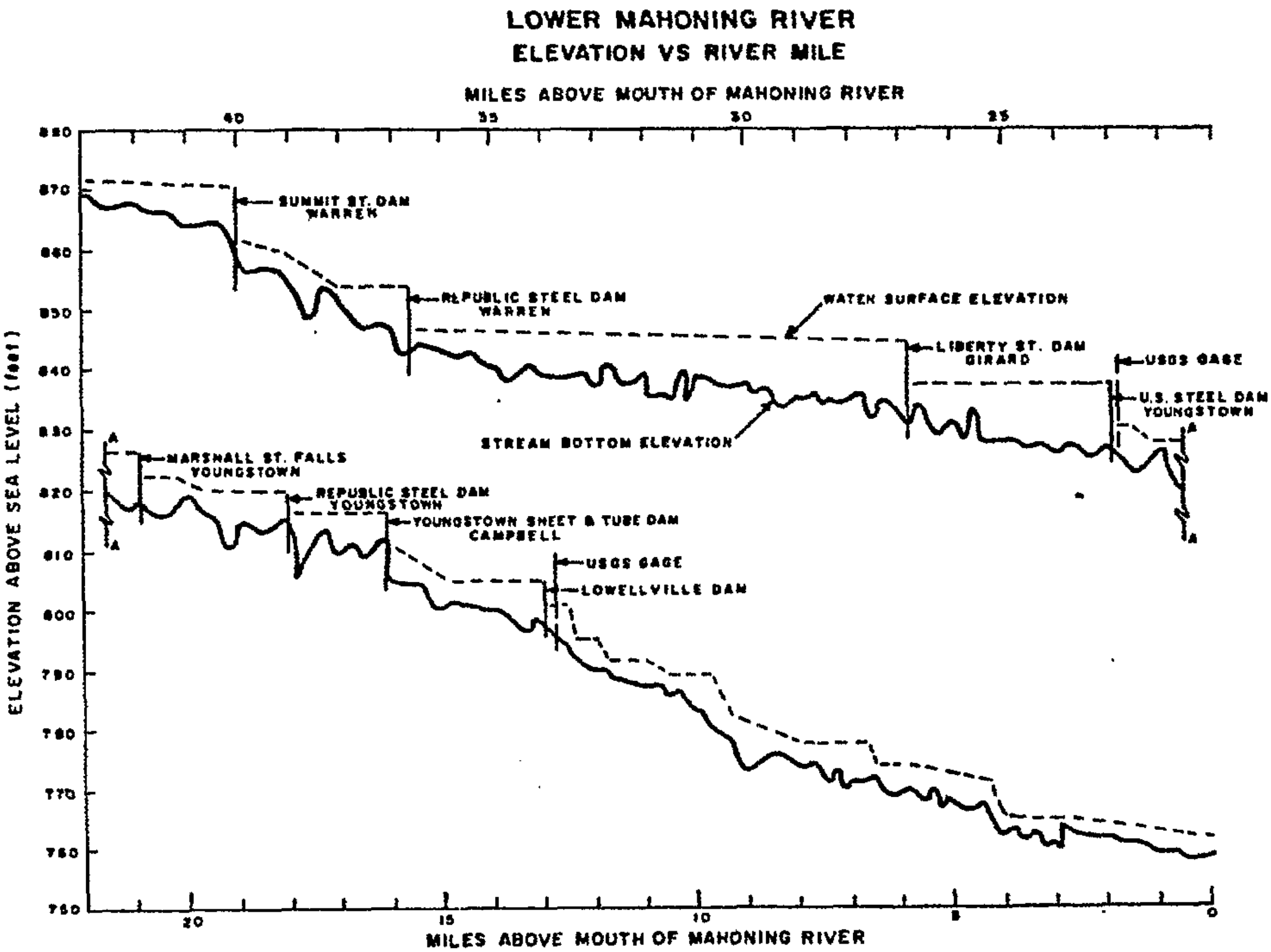

Figure 1. Longitudinal profile of the Mahoning River bottom and surface elevation above sea level. (Redrawn from OEPA, 1986. P 2-9; after Amendola et. al. 1977).

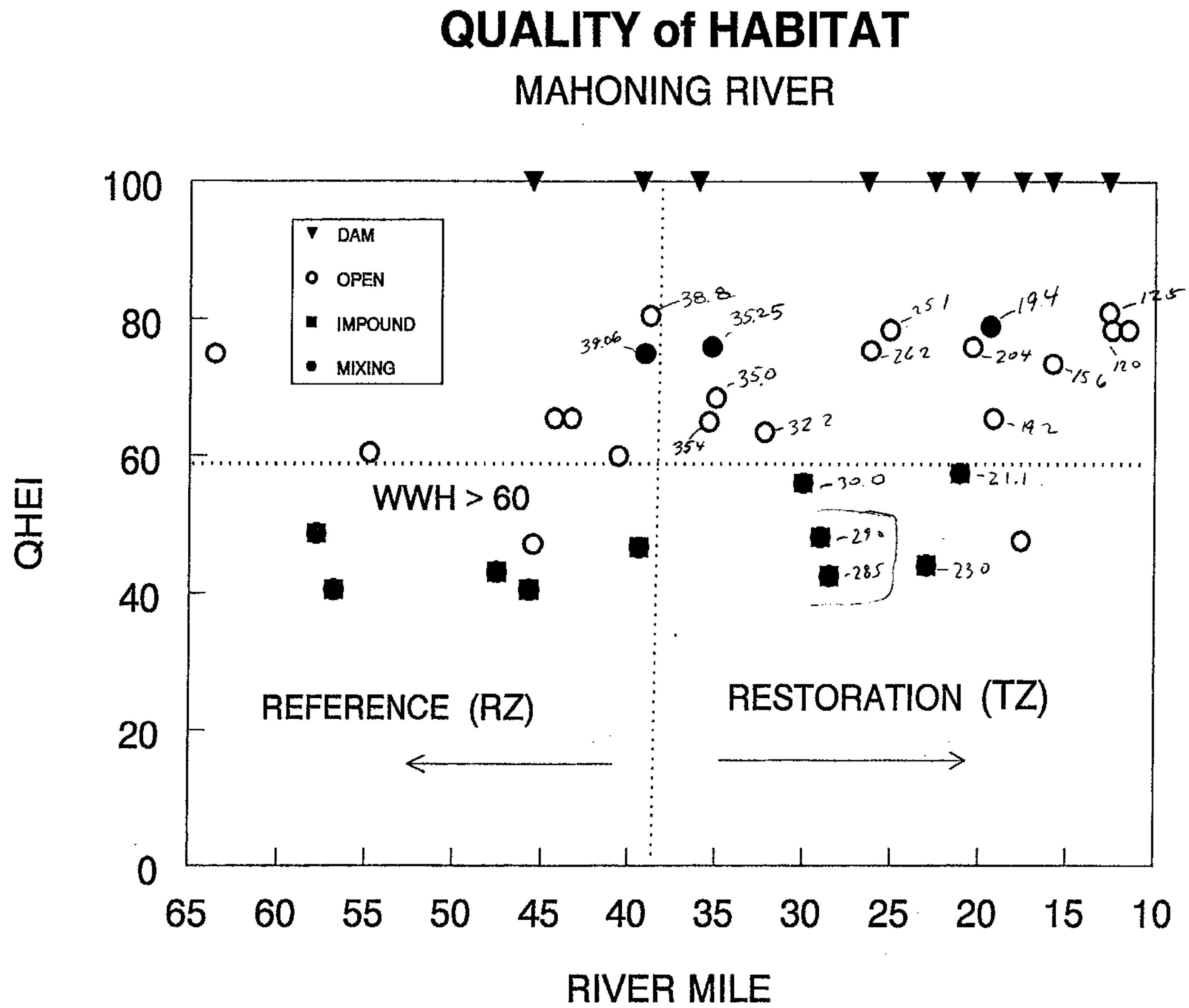

Figure 2. Qualitative Habitat Evaluation Index (QHEI) for the Mahoning River

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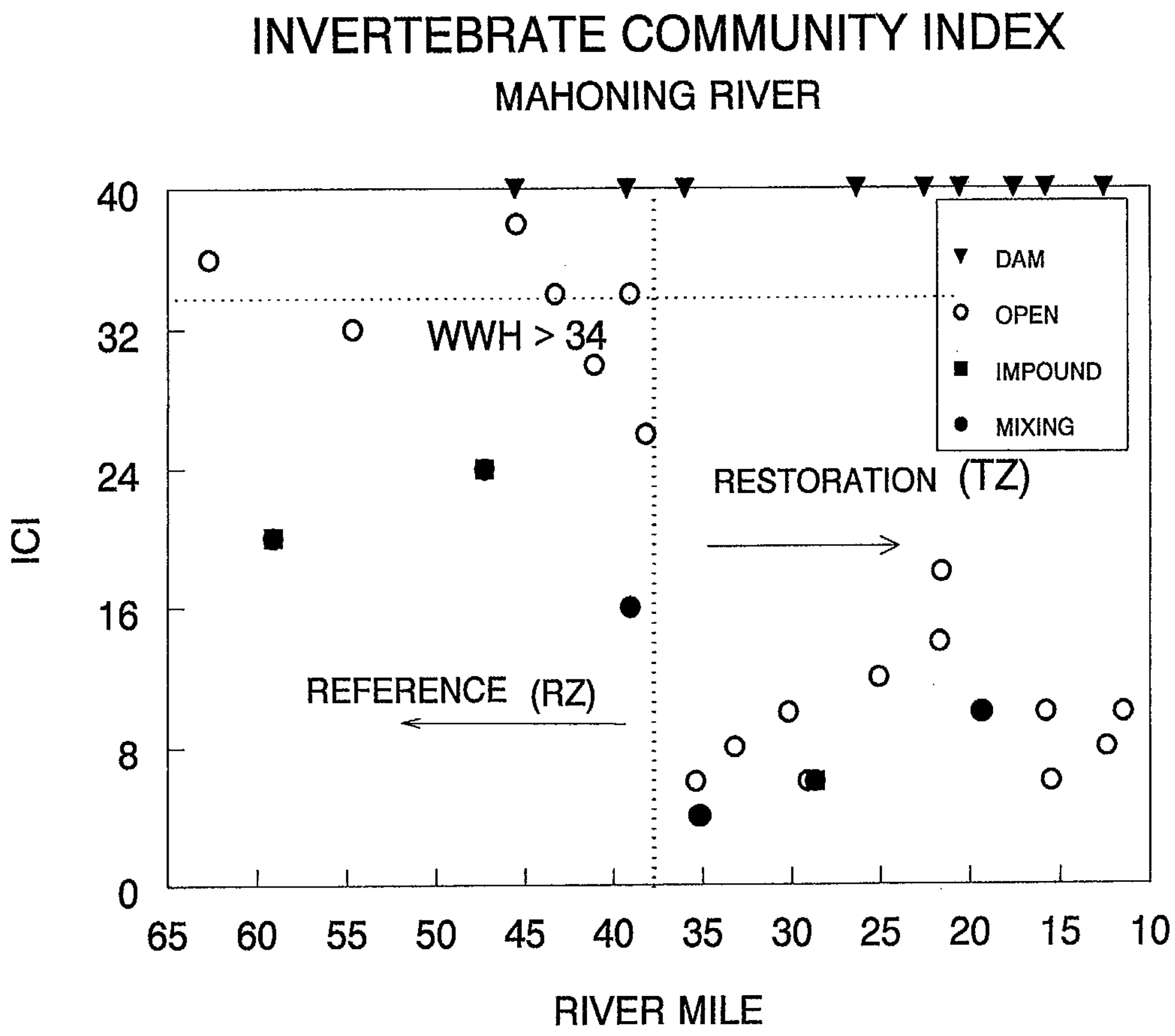

Figure 3. Invertebrate Community Index, (ICI).

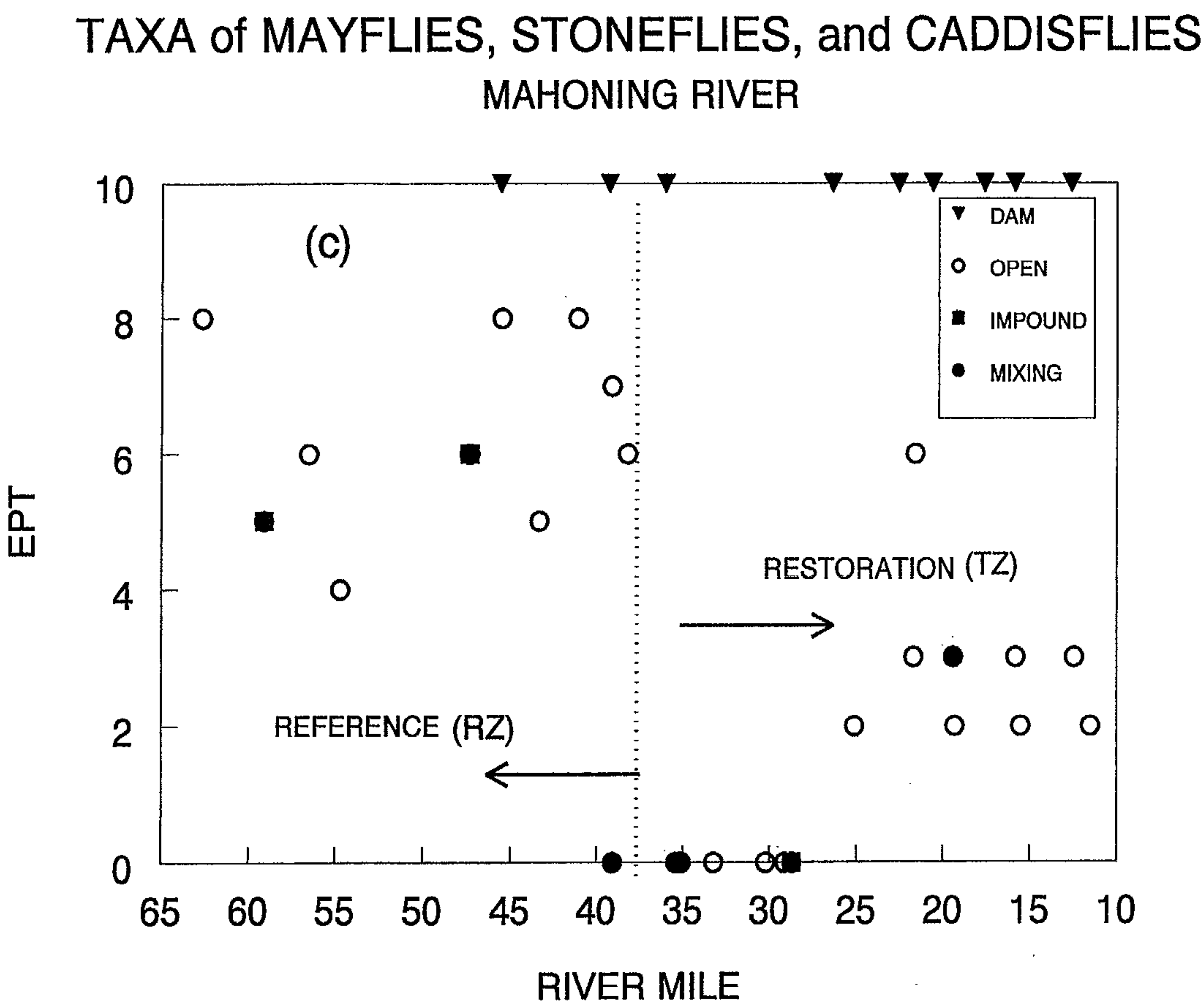

Figure 4. Sum of the taxa of Ephemoptera, Plecoptera, and Tricoptera, (EPT).

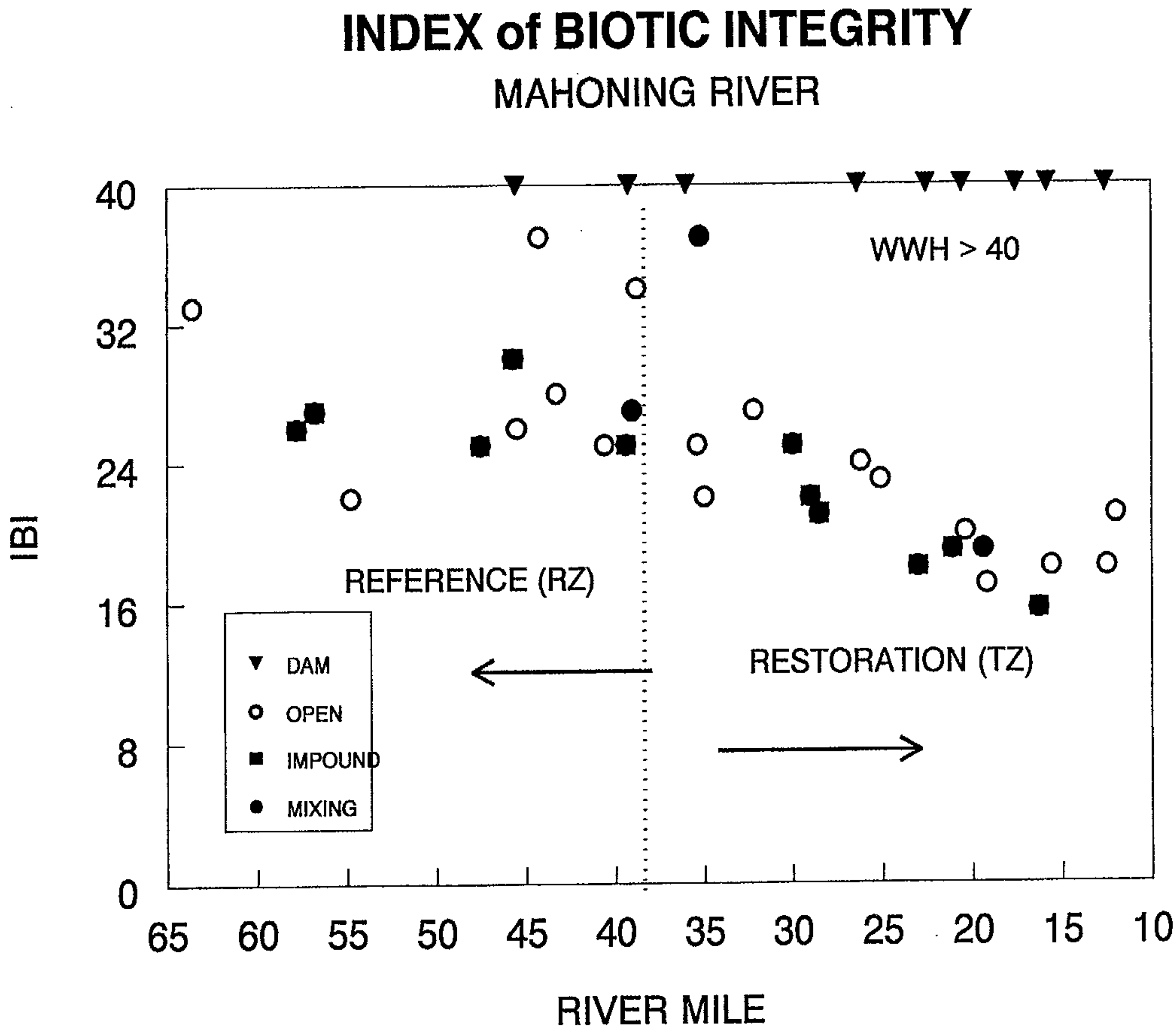

Figure 5. Index of Biological Integrity, (IBI)

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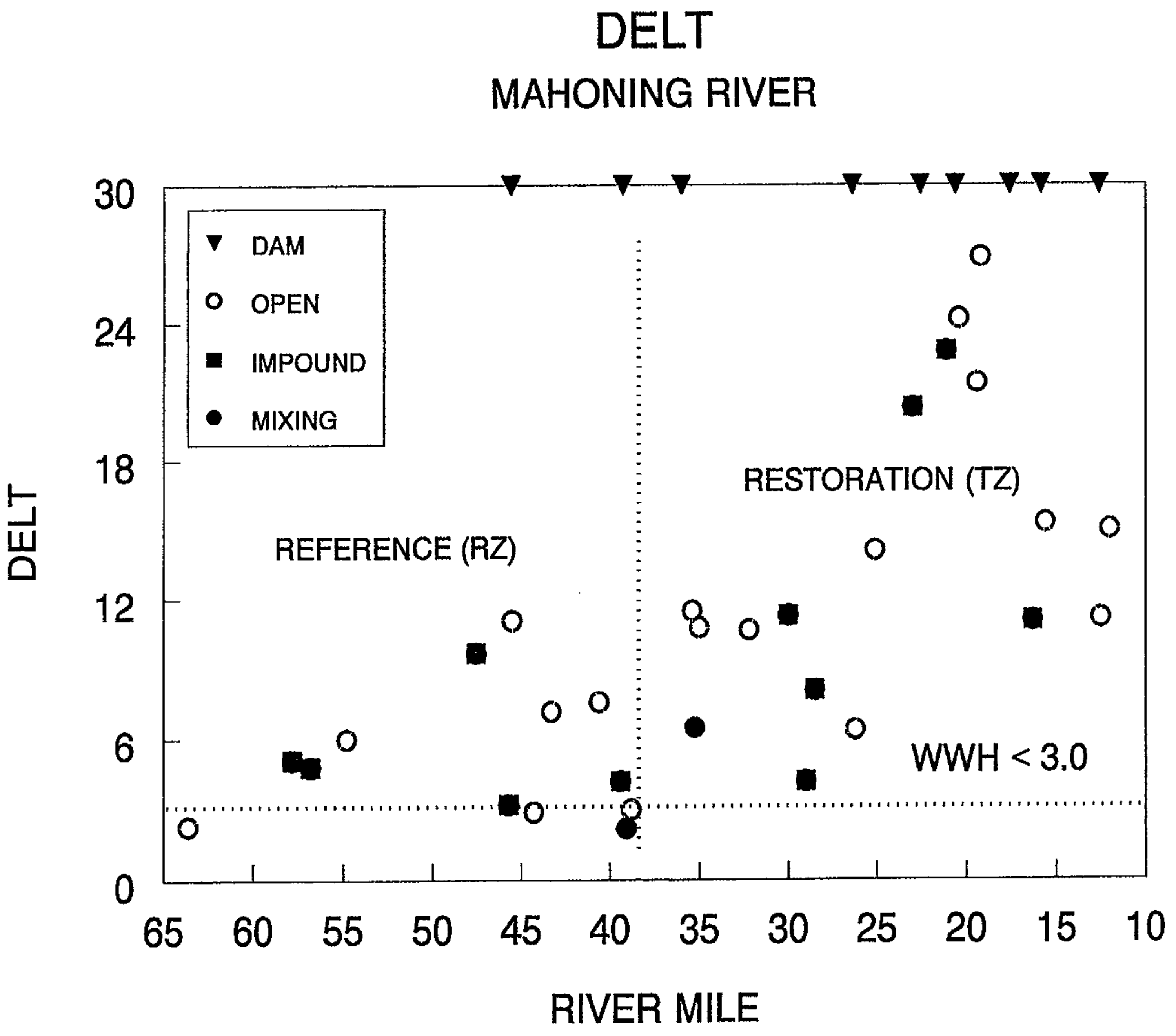

Figure 6. Percentage of fish with: Deformities, Erosion, Lesions, or Tumors, (DELT).

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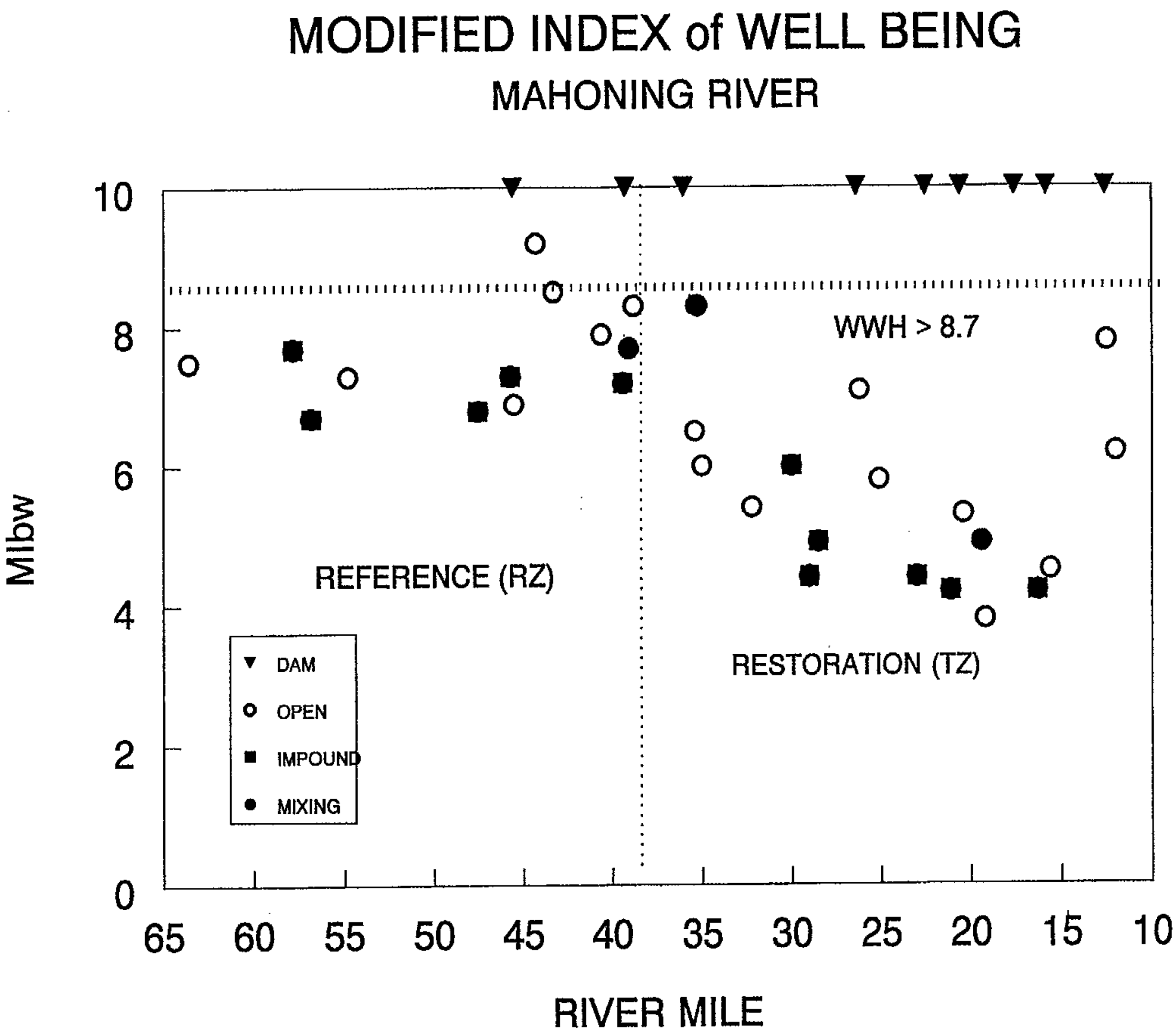

Figure 7. Modified Index of Well Being, (MIwb).

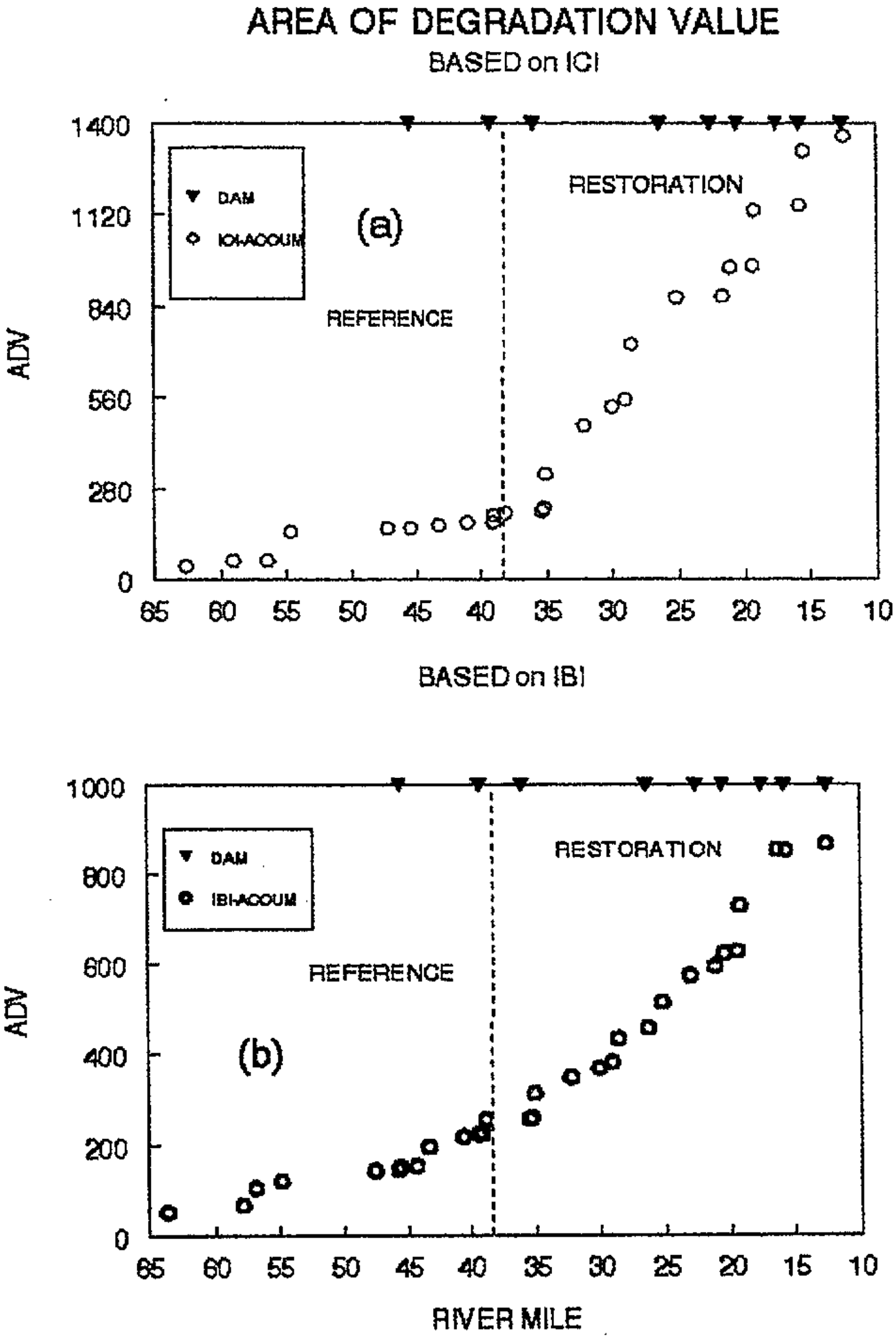

Figure 8. Cumulative Area of Degradation Values, (ADV), based on (a) the Index of Biological Integrity and (b) the Invertebrate Community Index. Demarcation between the "Reference Zone" and "Restoration Zone" is River Mile 38.